

FUEL-INJECTOR/AIR-SWIRL CHARACTERIZATION*

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INTRODUCTION

The objectives of this program are to (1) establish an experimental data base documenting the behavior of gas turbine engine fuel injector sprays as the spray interacts with the swirling gas flow existing in the combustor dome, and (2) conduct an assessment of the validity of current analytical techniques for predicting fuel spray behavior. Emphasis is placed on the acquisition of data using injector/swirler components which closely resemble components currently in use in advanced aircraft gas turbine engines, conducting tests under conditions which simulate or closely approximate those developed in actual combustors, and conducting a well-controlled experimental effort which will comprise using a combination of low-risk experiments and experiments requiring the use of state-of-the-art diagnostic instrumentation. Analysis of the data is to be conducted using an existing, TEACH-type code which employs a stochastic analysis of the motion of the dispersed phase in the turbulent continuum flow field.

APPROACH

The objectives of the program are to be achieved through the conduct of the following technical tasks:

1. An appropriate test configuration and the equipment and instrumentation required for documenting the two-phase flow within the configuration will be identified and assembled.
2. A sensitivity analysis will be conducted to establish which parameters should be varied in the test effort and what parameter ranges should be studied.
3. Tests will be conducted to verify the operation of the instrumentation under the conditions to be found in the data base tests. A data base will be established which will document the behavior of the two-phase flow under a number of selected conditions.
4. The acquired data will be analyzed using a TEACH-type analysis, and improvements to the physical models employed will be sought which will provide improved agreement between prediction and experiment.

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TEST APPARATUS AND INSTRUMENTATION

The experiments will be conducted within a section in which flow representative of that in a gas turbine combustor is generated (Fig. 1). Primary airflow enters through a swirler/nozzle assembly and undergoes a sudden expansion. Secondary flow is introduced in a direction normal to the flow section axis at an appropriate downstream location (beyond the region where the fuel spray/swirl-air interaction occurs). This configuration, termed the "model combustor" configuration, is intended to establish a flow having aerodynamic characteristics (velocities, turbulence intensities, turbulence scales, swirl strength and existence of recirculation regions) which are similar to, but of a less complex nature, than those of a real gas turbine combustor, and in which the flow is suitable for use in studying spray dynamics. A photograph showing the installation of the model combustor is shown in Fig. 2.

A two-component laser velocimeter will be used to acquire velocity field data for the gas phase and dispersed phase flows. The system utilizes a 1 watt argon-ion laser, prism-based color-splitter optics, and Bragg cells to generate the probe volumes (Fig. 3). In the case where single-phase flow measurements are performed horizontal and vertical diametral traverses will be used to acquire three components of velocity. Forward scatter optics will be employed to maximize signal-to-noise ratios. In the case where two-phase flow measurements are performed a fluorescent seed material will be employed, and a single probe volume will be established using the 488 nm blue beams. One set of optics will be employed to collect the Mie-scattered signal from the dispersed phase, and the second set will be used to collect the fluorescent emission from the seed which tracks the gas flow.

A high speed particle counter will be used to acquire information on the concentration of the dispersed phase for tests conducted with monosized particles. A particle passing through the velocimeter probe volume will trigger a counter when the DC level of the received signal exceeds a threshold level. The particle count, the elapsed time, and the sampling volume cross-section will be used to obtain a particle count flux which can be converted to particle concentration using the known particle size and velocity. For the monodisperse particles, a single setting of the threshold signal level will be a suitable criterion for rejecting particles not in the sampling volume.

A single-component droplet-sizing interferometer will be used to acquire information on the size and velocity of droplets produced when using liquid fuel. The instrument gathers spatially-precise, correlated, statistical data regarding the velocities and size of droplets passing through a probe volume formed by the introduction of two laser beams. The basic hardware employed by the phase/droplet particle analyzer includes transmitting optics, receiving optics with detectors, electronic signal amplifiers, filters, signal processor, and data management system. A schematic diagram of the apparatus is given in Fig. 4.

The two-dimensional, spatial distribution of the liquid and vapor phase concentrations of the injectant will be determined using quantitative laser-induced exciplex fluorescence. This technique is based upon the single-frequency laser excitation of fluorescence which occurs at two widely separated emission bands from each of the two phases. A pulsed neodymium-YAG laser system equipped with a fourth harmonic generating crystal will be employed in this effort. This laser is capable of delivering over 50 millijoules of laser energy at a wavelength of 266 nanometers at a repetition rate of 10 Hz. A 256 x 256 photoelectric array detector will be used to record the information produced by the fluorescence process. Final computer processing of the data will result in data arrays providing values of the liquid and vapor concentration in the field of illumination at an instant of time. By combining information gathered by a large number of realizations, information on time-averaged concentrations is acquired, and a statistical evaluation of the variation about the mean can be generated. A schematic diagram showing the principal elements of the measurement system is shown in Fig. 5.

TEST MATRIX

An analysis of the two-phase flow field to be generated within the model combustor was conducted to determine the appropriate baseline values and ranges of parameters to be employed in the tests. The analysis was conducted using PW-TEACH (Ref. 1) which uses a stochastic calculation procedure (Ref. 2) to track the interaction of the dispersed phase with the turbulent gas eddies. Results of a typical calculation are shown in Fig. 6 where the influence of primary zone swirl angle on injectant distribution is presented. For purposes of clarity, the results of trajectory calculations for only a few classes of particles are shown, and the assumption that particles striking the wall do not rebound was employed. These results indicated that the swirler discharge flow angle should be relatively low, e.g., 30 deg, to avoid the situation where a large portion of the spray is centrifuged to the test section walls. Other factors shown to have a primary influence on spray distribution were particle diameter and specific gravity. Combustor pressure drop was predicted to have a lesser effect. Spray cone angle, injection velocity, and injectant carrier gas mass flow were found to have only minor influences.

The test matrix generated using the results of the sensitivity analysis is given in the following table:

TEST MATRIX - DATA BASE ACQUISITION

Test No.	Type	Swirl Angle (Deg)	Pressure Drop (%)	Temp. (C)	Injectant	Instrument	Comment
1	Aero only	30	2	21	-	LV	Baseline-gas only
2		45	2	21	-	LV	High swirl
3		30	4	21	-	LV	High pressure drop
4		30	2	316	-	LV	High temperature
5	Spray only	0	0	21	30/38S	LV,C	Microspheres
6		0	0	21	35 L	LV,DSI	Baseline-Liquid
7	2-Phase, Micro-spheres	30	2	21	30/38S	LV,C	Baseline - Particles
8		30	2	21	53/62S	LV,C	Large particles
9		30	2	21	20/30S	LV,C	Small particles
10		45	2	21	30/38S	LV,C	High swirl
11		30	4	21	30/38S	LV,C	High pressure drop
12	2-Phase, Liquid	30	2	316	35 L	X,DSI	Baseline - liquid
13		30	2	316	57L	X,DSI	Large droplet
14		30	2	316	22L	X,DSI	Small droplet
15		30	2	150	35L	X,DSI	Low temperature
16		30	2	150	57L	X,DSI	Low temperature, Large droplet
17		30	2	150	22L	X,DSI	Low temperature, Small droplet

Legend

Injectant: S = Microspheres L = Liquid Pentane
 Instrumentation: LV = Velocimeter C = Concentration Measurement
 X = Exciplex Fluorescence
 DSI = Droplet Sizing Interferometer

CURRENT STATUS

Activities are currently underway to verify the operational capabilities of the instrumentation. The verification tests for the laser velocimeter and particle concentration measurement system are being conducted using a pipe-flow test apparatus within which a two-phase flow having known characteristics will be developed (Fig. 7). The objective of the velocimeter tests will be to establish that the technique of using a fluorescent seed material is workable under the conditions of flow velocity, particle size, and particle loading to be present in the data base acquisition tests.

Tests are being conducted using two types of fluorescent seed: 1) polymer-encapsulated dye and 2) liquid dye seed. The polymer-encapsulated

dye is a proprietary material supplied by Eastman Kodak. The material has been prepared both as a dispersion in an aqueous solution, and as a dried material. The size distribution of the material in aqueous solution determined by use of a disk centrifuge technique and by transmission electron microscopy, is 0.1 to 2 microns. The dried form is more nearly monodisperse, in the size range from 2-3 microns, and the particles are roughly spherical in shape. Tests are also being conducted to establish the time response characteristics of the seed material. To be effective as a velocimetry seed, the fluorescence emission rise time and decay time must be on the order of tens of nanoseconds or less in order to follow the fringe pattern established in the sampling volume. Measurements of the fluorescence burst resulting from illumination by a pulsed laser indicate the characteristic time meets these requirements.

Liquid fluorescent dye has previously been used as a seed material for single-phase flow, but potential problems exist which must be evaluated before this approach can be applied in a two-phase flow having the characteristics of a gas turbine combustor primary zone. Tests are underway to establish that the liquid seed will not be scrubbed out of the flow by the large concentrations of particulate material that the dye coating on the large particles does not produce a velocimeter signal which would bias the results of the gas phase measurements and that micron-sized dye particles will be present in sufficient concentration at the test section site, having been injected at some far upstream location.

In related activities, efforts are underway to verify the operational capability of the exciplex fluorescence imaging system. Tests will be conducted using a single droplet test device (Fig. 8) in which the vapor cloud surrounding a vaporizing droplet can be examined. Verification of the capability of the instrument will be achieved when the vapor concentration level deduced from the measurement is found to agree with that predicted analytically for the case of the vaporization of an isolated droplet. Pentane droplets will be injected into a co-flowing heated nitrogen stream in these experiments.

References

1. Sturgess, Geoffrey J.: Aerothermal Modeling Program Final Report, NASA CR-168202.
2. Gosman, A. D. and Ioannides, E.: Aspects of Computer Simulation of Liquid-Fueled Combustors, AIAA 81-0323, January, 1981.

AXISYMMETRIC MODEL COMBUSTOR CONFIGURATION

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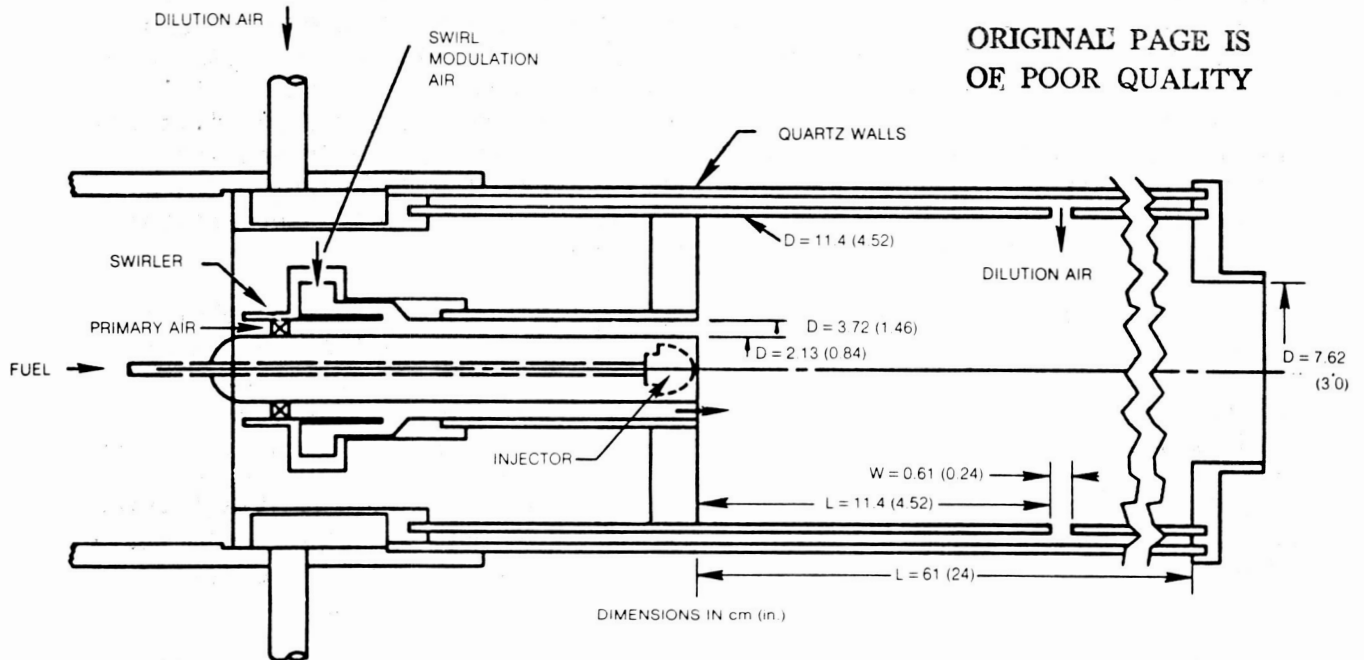


Figure 1

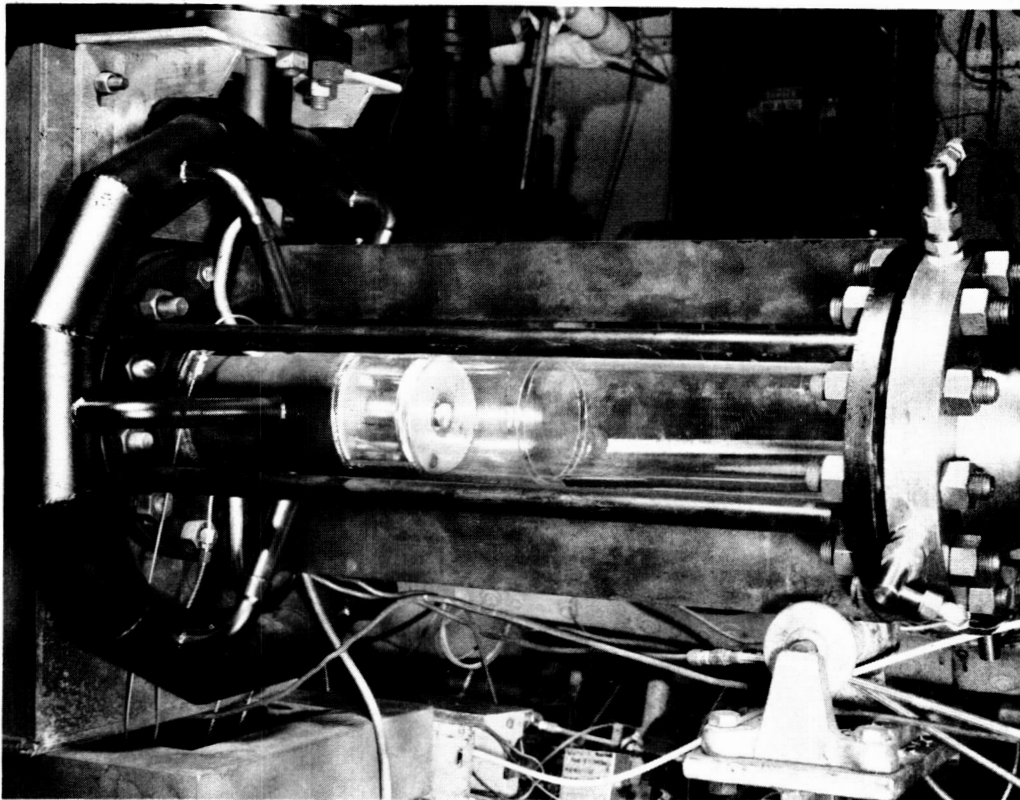


Figure 2

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LASER VELOCIMETER SYSTEM

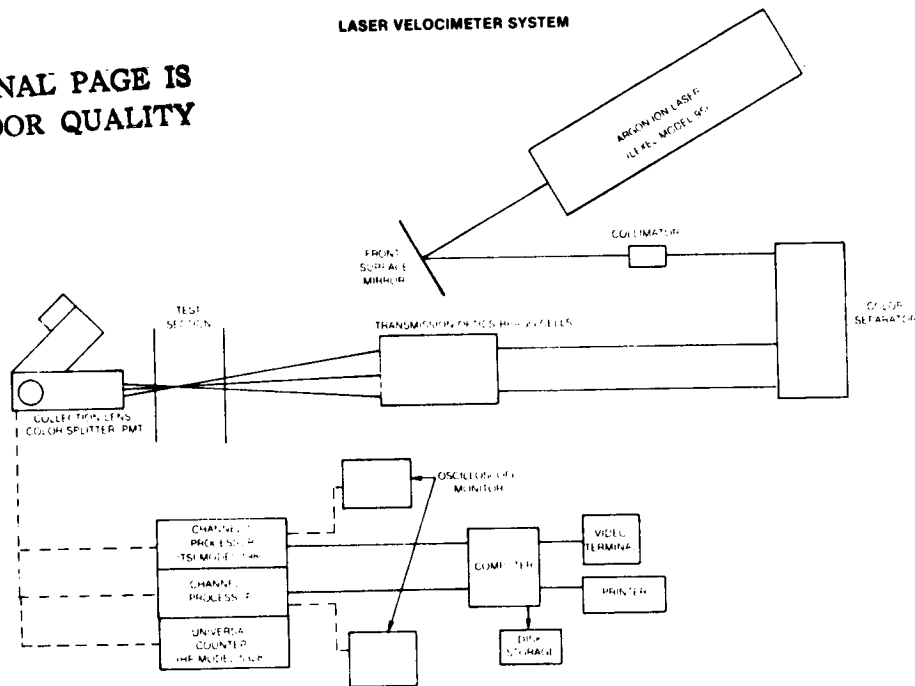


Figure 3

PHASE/DOPPLER PARTICLE ANALYZER

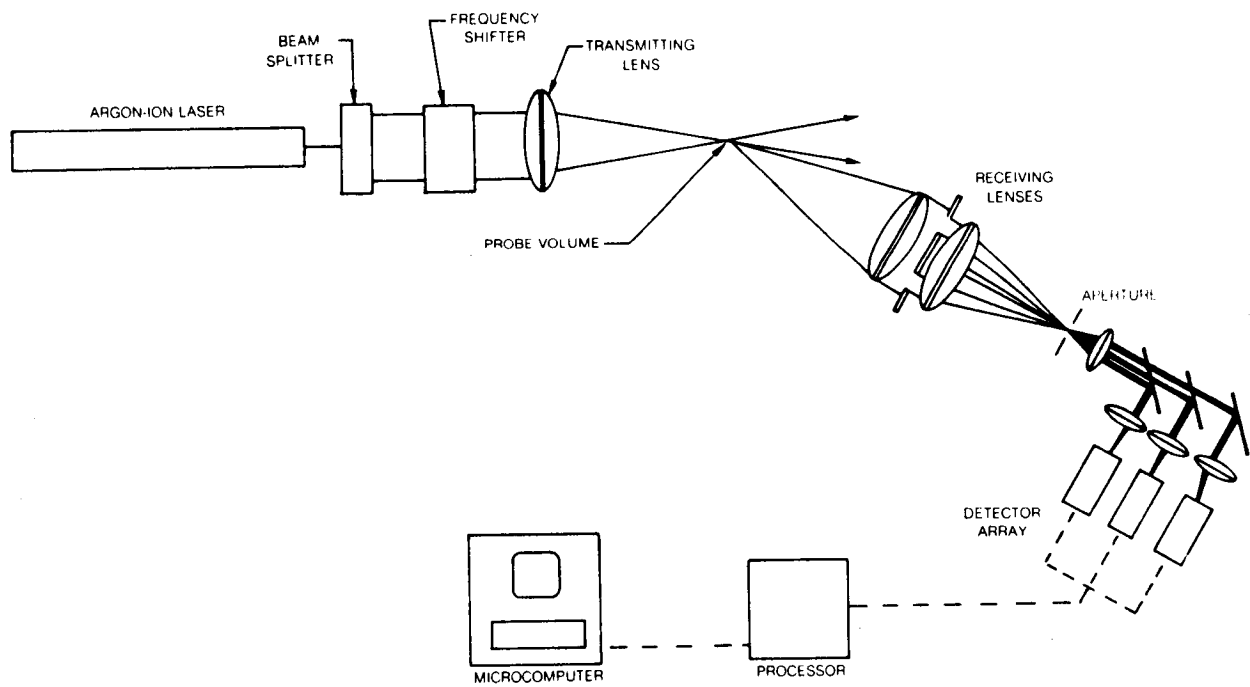


Figure 4

EXCIPLEX FLUORESCENCE SPRAY EVALUATION SYSTEM

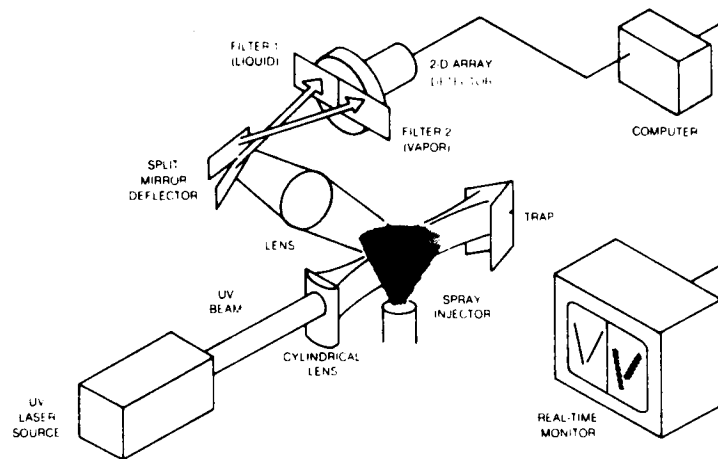


Figure 5

EFFECT OF AIR SWIRL ON PARTICLE DISTRIBUTION

PARTICLE DIAMETER = 34 microns
PARTICLE SPECIFIC GRAVITY = 1.5

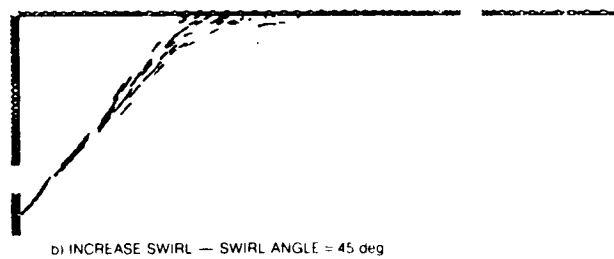
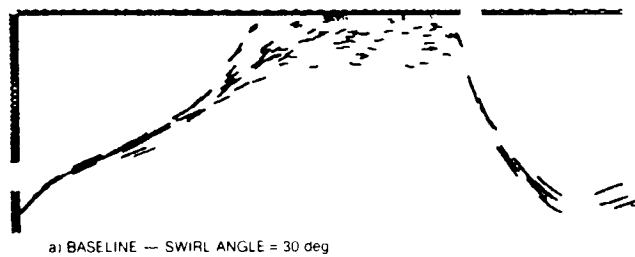


Figure 6

PIPE FLOW TEST APPARATUS

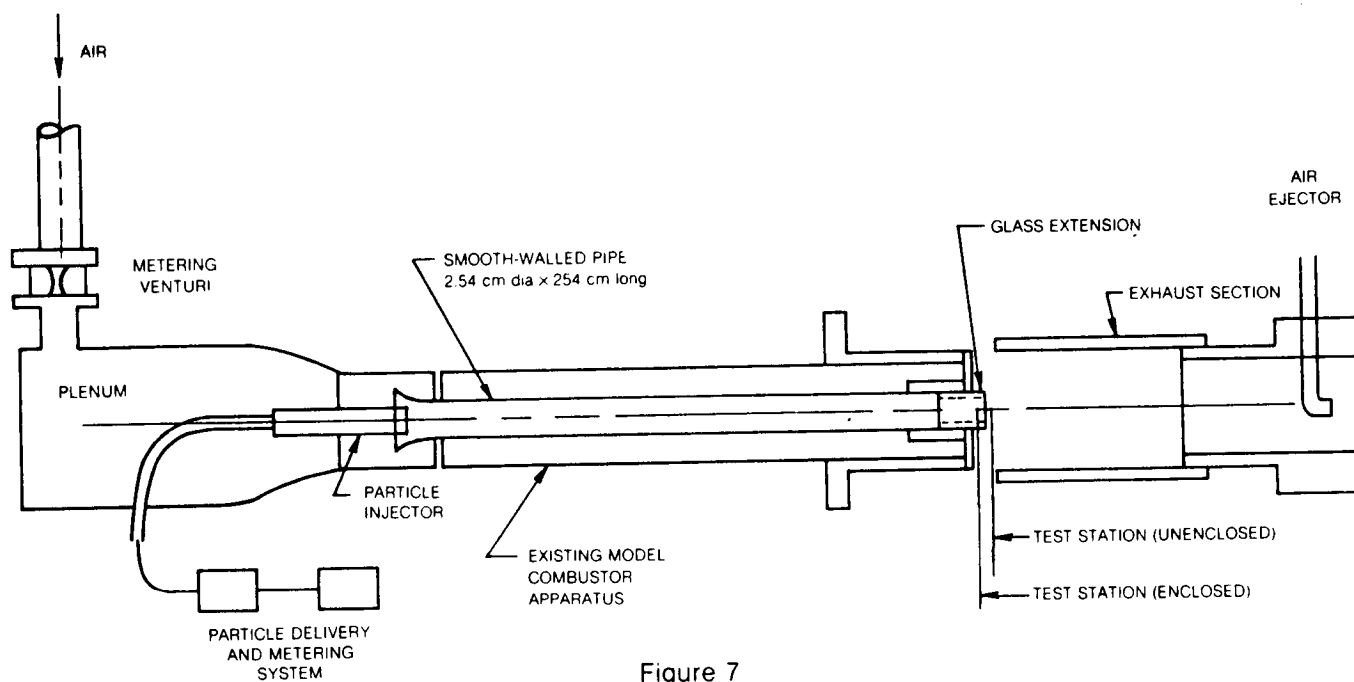


Figure 7

SINGLE-DROPLET TEST DEVICE

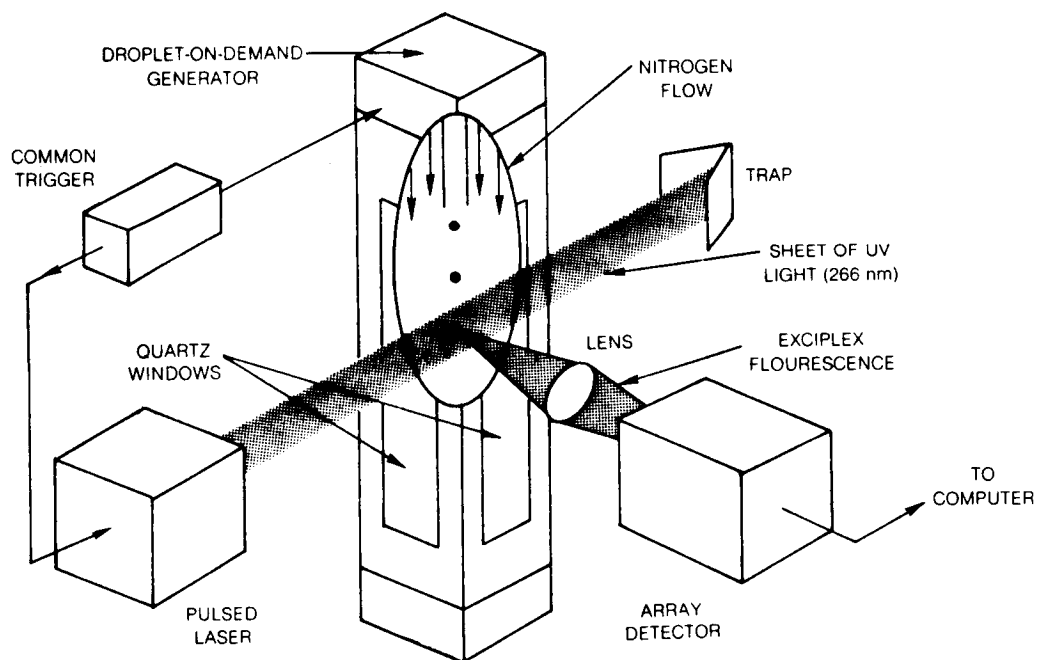


Figure 8